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Analysis of the Variable Sources Observed by IRAS

This report covers the period from July 1992 through June 1993.

1. resolution of multiple associations

Most of the approximately 7000 known optical variables in the ICVS were associated with only one IRAS source within the default 60 arcsec search radius. However, some variables were associated with more than one IRAS source and some IRAS sources were associated with more than one known variable. There were fewer than 300 of these multiple associations. These multiple associations could often be resolved by considering the actual separation between the known variable and the IRAS position, and by considering the brightness and colors of the IRAS source. In those rare circumstances where this simple approach could not resolve the multiple associations, the IRAS positional error ellipse was used. Several dozen cases of multiple association were resolved in this manner and in all cases a unique match was possible.

2. the new IRAS variables (NIVs)

We have discovered more than 10000 new IRAS variables (NIVs). These new variables were identified by considering the parameter VAR as reported in the Point Source Catalog (PSC). This parameter is simply an estimate of the % probability that a source was indeed variable. An examination of the distribution function for this parameter for the PSC reveals quite clearly that two distinct populations are present. First, there is a population of non-variable objects with a broad peak near VAR=0. The half-width of this peak occurs at about VAR=20% and a slow steady decline continues until a constant level is reached at about VAR=60-70%. The second peak is extremely strong and narrow at VAR=99%. This peak declines rapidly for lower VAR values and reaches values comparable to the 60-70% level by VAR=90%. Thus, for our purposes, a variable IRAS source is considered to be a source with VAR>90%. We define the NIVs to be those sources with VAR>90 and for which no positional association exists with an object in the GCVS. We have extracted these sources from the PSC and have added them to the ICVS.

The ICVS now consists of 11468 NIVs as well as 7627 previously known variables (PKVs). This implies that roughly 5% of all sources detected by IRAS in the far-infrared appear to be variable. Furthermore, only about 10% of the NIVs have positional associations with any other known objects. That is, most of the NIVs have no known optical counterparts.

It is expected that a search for associations with the HST Guide Star Catalog will surely diminish the number of unassociated sources. Furthermore, it is also expected that many NIVs will also be found to have associations with the new faint Mira variables being discovered by MacConnell (personal communication) as a part of a deep spectral survey of the galactic plane.

The galactic distribution of the NIVs reveals that these sources are concentrated in the plane and in the bulge of the galaxy. While crowding and confusion in the plane is likely to make some non-variable sources appear to be erratically variable, a preliminary examination of the time-series HCON data for a sample of NIVs indicates that most sources exhibit a steady increase or decrease rather than sporadic or irregular behavior.

Finally, an examination of the far-infrared color-color planes reveals that the NIVs exhibit a distribution slightly different from the GCVS optical variables (the PKVs). A comparison of the [25]-[60] vs. [12]-[25] diagram with results reported by Habing (1989) suggests that the NIVs may be dominated by OH/IR stars. A second population of NIVs appears similar to a heavily reddened population of Mira variables. The vertical sequence in this diagram appears to correspond to the galactic Miras but reddened by about 1 magnitude in [12]-[25]. This reddening could be interstellar, it could be circumstellar, or it could represent a real population difference between the NIV Miras and the known galactic Miras. A heavily populated diagonal plume extends toward the upper right and seems to correspond with the OH/IR stars. However, here again, this sequence seems reddened by about 1 magnitude in [12]-[25] with respect to the known galactic OH/IR stars.

A third sequence in this diagram appears as a lose scattering of sources along the top of the diagram with [25]-[60] > 3.5. These extremely red colors are typical of HII regions or knots of nebulosity or infrared cirrus. Indeed, the galactic distribution for this third class of sources is tightly concentrated within about 5° of the galactic plane as well as being concentrated in the vicinity of the LMC. We believe that these sources are not true point sources and reflect the inevitable confusion expected in highly crowded regions. Since this third population comprises less than 15% of the total population of NIVs, we believe that most of the NIVs in the ICVS are indeed truely variable point sources in the disk and central bulge of our galaxy.

Habing (1989) From Miras to Planetary Nebulae: Which Path for Stellar Evolution?

3. IRAS detection statistics for variable stars

Detection statistics were derived for all the variable stars detected by the IRAS satellite. These statistics were compared with the numbers of variables known and cataloged in the General Catalog of Variable Stars (GCVS). In general terms, IRAS detected 26% of all the previously known variable stars cataloged as of 1984. For example, IRAS detected 32% of all the known RV variables, 42% of all the SR variables, and 54% of all the known Mira variables. Thus, IRAS detected nearly 50% of all the known long-period red variable stars in the galaxy. For the hotter and less luminous pulsating stars, IRAS was not quite as effecient. IRAS detected only 20% of the known β Cep stars, 18% of the classical Cepheids, and 9% of the δ Sct stars.

4. Color-color diagrams

Software has been developed to derive and plot the far infrared color-color diagrams for sources in the ICVS. The diagrams adopted are the [25]-[60] vs. [12]-[25] and the [60]-[100] vs. [25]-[60] diagrams as introduced by Walker and Cohen (1988) since in this system normal stars have colors near zero. In this system emission from circumstellar dust causes objects to have colors significantly greater than zero so that objects surrounded by dust shells are easily identified. We are attempting to identify occupation zones in these diagrams for the different types of variable stars. Unfortunately, this task is complicated by the fact that some known variables appear to have dust shells while other objects of the same type appear like normal stars. However, it does appear that several well defined sequences appear in these diagrams; and although simple attempts to correlate position along a sequence with period have not been successful, it is still believed that the sequences may represent some form of evolution.

Walker and Cohen (1988) AJ 95, 1801

5. HCON data for PSC sources in the ICVS

We have extracted all the individual HCON data from the WSDB for all the sources in the ICVS. The HCON data is the individual "hours confirmed" observations obtained by IRAS. The HCONs may be thought of as the individual observations on which the data in the ICVS is based. Since IRAS essentially made three complete passes of the entire sky, there are normally three HCONs for each source in the PSC. However, because of the scanning mode adopted by the satellite, for sources close to the ecliptic poles there can be 5 or 7 or even more HCONs. Since the time is recorded along with each HCON observation, the HCON data basically comprises time series observations for the IRAS sources. For the 19151 sources in the ICVS this amounts to approximately 8 MB of data. We are currently evaluating the interest and feasibility of distributing this data as auxiliary files along with the main ICVS catalog. The ICVS itself is currently about 4.2 MB.

6. Maximum 12μ flux and range extracted from the HCON data

Using the HCON data, the maximum 12μ flux and the 12μ flux range (both in Janskys) have been extracted for all sources and added to the ICVS. Thus, the ICVS contains the visual (or photographic) maximum and range (in magnitudes) and the 12μ maximum and range (in Janskys).

7. Time variability plots

Software has been developed which can display a "time variability plot" for any of the sources in the ICVS. This is basically a plot of the variability of the source during the IRAS mision. Basically, this software can extract data for an IRAS source name from the HCON data files. An output file is generated which consists of the Julian date, the flux values at 12, 25, 60, amd 100μ, and the 1-sigma statistical errors for each of the flux values. Additional software has been developed which can display this data using the graphics package MONGO in an xterm window on a SparcStation. The four bands are plotted on the same plot using different symbols and special symbols are used to represent flux data which is merely an upper limit.

If the decision is made to distribute the HCON data for the ICVS along with the primary ICVS catalog, this software for extracting time-variability data will be provided along with the basic data.

8. a new period-luminosity relationship for classicial Cepheids

We have used data from the ICVS to investigate the period-luminosity (PL) relationship for classical Cepheids at a wavelength of 12 μ. For ease of comparison with PL relationships at other wavelengths, we have used the absolute magnitude at 12 μ as the luminosity indicator for this calibration.

$$M(12) = -2.5 \log(F_{12})$$

Here F_{12} is the absolute flux in Janskys which may be directly obtained from the 12 μ flux in Janskys as reported in the ICVS as long as the distance to the object is known. For this version of the PL relationship, Cepheid distances were taken from the review by Feast and Walker (1987). Thus, the zero-point for this PL relation is based on the distances to cluster Cepheids assumed by Feast and Walker, while the slope of the relation is based on the 12 μ fluxes observed by the IRAS satellite. The resulting relationship is:

$$\begin{array}{lcll} M(12) & = & -9.86 & -3.65\ (\log P - 1) \\ & & \pm 0.06 & \pm 0.13 \end{array}$$

The dispersion about this mean relation is ±0.25 magnitude and is based on 19 classical Cepheids. This is comparable to dispersions quoted for other modern determinations of the PL relationship and when combined with the reported photometric precision of the 12 micron fluxes in the ICVS amounts to a 12% uncertainty in distances obtained using this relation.

For comparison, the same 19 objects were used in conjunction with data reported by Feast and Walker to derive a PL relationship for the V band. This relationship is:

$$\begin{array}{lcll} M(V) & = & -4.18 & -2.92\ (\log P - 1) \\ & & \pm 0.04 & \pm 0.09 \end{array}$$

Here the formal dispersion is ±0.17 magnitude.

These results compare quite favorably with results for a sample of 25 LMC Cepheids as reported by Madore and Freedman (1991). For these LMC objects the derived slope was -2.88(±0.20) and the dispersion was ±0.29 magnitude for V band observations.

However, the advantage of the 12 micron PL relationship is its simplicity. No corrections are required for the effects of interstellar extinction, nor must any corrections be applied to reduce random phase observations to some assumed mean light level. That is, one does not need to obtain a well sampled light curve, and there is no uncertainty associated with reddening corrections since no reddening corrections need to be applied in the far-infrared. This is because the interstellar grains which produce the visual obscuration become virtually transparent at wavelengths beyond 10 microns. Furthermore, the mean of a few random phase observations at 12 microns is quite acceptable since the amplitude of the light variation becomes significantly diminished in the far-infared. It is important to note that while the V band data used in this comparison has been highly corrected for interstellar extinction and for the mean light levels for each object, no such corrections have been applied to the 12 micron data. Indeed, the 12 μ data has simply been taken from the ICVS without any corrections whatever.

The distance scale implied by the 12 micron PL relationship is in good general agreement with Cepheid distances determined using other techniques or relationships. Of historical interest is the classic distance scale implied by the compilation of basic Cepheid data by Fernie and Hube (1968). In a plot of the 12 μ distances versus the distances reported by Fernie and Hube, a straight line with a 45° slope is the one-to-one relation which would apply if the distances were equal. Points falling to the lower right of this line may be under corrected for interstellar extinction or may be contaminated by 12 μ infrared cirrus. Such contamination makes an object appear too bright since processing of the IRAS survey data did not completely remove the background for a point source embedded in bright nebulosity. Some combination of these effects has caused marked discrepancies for a handful of points at ICVS distances between 500 and 1000 pc. While the two scales show marked agreement up to 800 pc, the deviant points at ICVS distances greater than 1000 pc are most likely due to under estimating the effects of extinction. The mean fractional difference in the distance scales is +0.79. This implies that the Fernie and Hube distance scale is on the average 79% greater than the ICVS distance scale. However, the main contribution to this difference is the handful of deviant points between 500 and 1000 pc.

We have also compared the ICVS distance scale with the scale inferred in the work by Caldwell and Coulson (1987). The Caldwell and Coulson distance scale uses a PL relationship that is constrained by a presumed galactic rotation curve, and Cepheid magnitudes and colors were corrected to a standard color and period in an attempt to correct for possible differences in chemical composition and radial distance from the center of the galaxy. The most deviant point at an ICVS distance of 1000 pc is RU Sct which is known to be contaminated by infrared cirrus. The mean fractional difference in these distance scales is -0.04 (4%), but since the ICVS scale is uncertain at the 12% level, this difference is not significant. The remarkable over-all agreement between these two distance scales suggests there is no need to resort to galactic kinematics or to special color corrections to obtain reliable distances to Cepheids.

In addition, we have compared the ICVS distance scale with a totally independent distance scale based on the visual surface brightness method as described by Gieren (1988). Again the distance scales seem to be completely consistent with a mean fractional difference of only +0.04 (4%). The Gieren scale covers a more restricted range in distance and is in general limited to brighter nearby objects since the method requires a well sampled radial velocity curve for each object. Again, the deviant point at an ICVS distance near 1000 pc is the cirrus contaminated data for RU Sct.

In conclusion, a PL relationship has been derived in the far-infrared at 12 microns which is able to produce distances good to 12% for classical Cepheids. The zero-point for the relation is based on the cluster distances and reddening corrections assumed by Feast and Walker (1987) for 19 Cepheids, but the slope of the relation is based on 12 micron fluxes obtained by the IRAS satellite. The form of the relation is completely consistent with similar modern determinations in the visual and near-infrared. The resulting distance scale shows remarkable agreement with independently determined distances for Cepheid variables. The principle advantage of the 12 micron relationship is the total absence of any correction for interstellar extinction and the proven ability to use a few random phase observations to obtain the apparent brightness.

Caldwell and Coulson AJ 93,1090 (1987)
Feast and Walker Ann. Rev. Astron. and Astrophys. 25,345 (1987)
Fernie and Hube AJ 73,492 (1968)
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